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Factors Influencing the Composition and Quantity of Passenger Car Refueling Emissions. Part 2

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FACTORS INFLUENCING THE COMPOSITION AND QUANTITY OF PASSENGER CAR REFUELING EMISSIONS - PART II

By

James N. Braddock
Atmospheric Sciences Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

ATMOSPHERIC SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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ABSTRACT

This study measured and characterized refueling emissions from a 1986 Pontiac Grand Am using 3 test fuels, including a winter, summer and intermediate blend gasoline under a variety of seasonal temperature conditions. It investigated three major parameters that affect refueling emissions: fuel volatility, expressed as Reid Vapor Pressure (RVP); dispensed fuel temperature (Td); and tank fuel temperature (Tt). In this study, RVP varied from 10.0 to 13.3 psi, Td varied from 50 to 88°F, and Tt varied from 40 to 108°F, while the overall hydrocarbon (HC) refueling emission rate ranged from 2.90 to 7.41 grams/gallon. Detailed hydrocarbon analyses were completed for both the test fuels (dispensed fuel and tank fuel) and the refueling vapor. The overall mean (from all test fuels and temperature scenarios) HC emission rate was 4.69 g/gal; the mean refueling vapor was comprised of 79.7% paraffins, 13.6% olefins, 5.8% aromatics, with an average carbon number of 4.76; overall mean test gasoline was comprised of 39.5% paraffins, 7.7% olefins 49.0% aromatics, with an average carbon number of 7.30. Butanes and pentanes comprised about 70% of the total HC refueling vapor.

In October, 1986 the Mobile Source Emissions Research Branch of the Environmental Protection Agency (EPA) reported the results of a study to investigate various experimental factors which could influence the composition and rate of emissions during laboratory simulation of passenger car refueling (1).* These factors included the fuel delivery rate, the fuel tank capacity and size, the source of emitted hydrocarbon (HC) vapor, the effect of fuel aging, and the effect of delivery fuel and vehicle tank temperature variation. The conclusions indicated that, 1) the vehicle fuel tank size, shape, configuration, and location; 2) the size and length of the fill tube; and 3) the fuel delivery rate had relatively little effect on the total mass of motor vehicle refueling emissions. The total mass of HC vapors emitted during vehicle fueling was primarily determined by the amount of fuel delivered to the fuel tank.

Refueling emissions were also dependent upon the temperature of both the delivered fuel and the fuel in the vehicle tank. Within the temperature ranges of the study, emissions generally increased with an increase in delivered fuel temperature and a decrease in vehicle tank fuel temperature. Findings of a brief examination of fuel aging suggested that emissions composition may be influenced by aging. In general, it was found that the relationship between the composition of refueling emissions and tank fuel volatility required further definition. Hence, a follow-on study was to be conducted by EPA to investigate this relationship while examining refueling emissions from typical fuels used in winter, spring, and summer under normal use conditions.

The follow-on study, reported here, details refueling emission rates from a 1986 passenger car using 3 test fuels including a winter, summer, and intermediate blend gasoline, under a variety of seasonal temperature

conditions. This study investigates the major parameters that affect refueling emissions. These parameters include: 1) fuel volatility, customarily expressed as Reid Vapor Pressure (RVP); 2) dispensed fuel temperature (Td); and 3) temperature of the fuel in the vehicle's tank prior to refueling, hereinafter referred to as tank temperature (Tt).

EXPERIMENTAL PROCEDURES

Vehicle Selection - The vehicle selected for use in this study was a 1986 Pontiac Grand Am with a fuel tank of 13.2 gallon capacity. The fuel tank was outfitted with a heat blanket, a drain valve, and thermocouples at the 5% fuel level (to detect gasoline liquid temperature) and at the 50% fuel level (to detect the vapor headspace temperature). The fuel tank, illustrated in Figure 1, was of a quadrilateral shape 44" long x 20" wide x 6" high with a fill tube length of 52" and diameter of 2". Gasoline flow into the fuel tank was carefully maintained at 5 gallons/minute (gpm) to avoid fuel spit-back, which was encountered while attempting higher (~8 gpm) flow rates.

Fuel Selection - Two unleaded fuels were used in this study, an Amoco winter grade gasoline and a Sun summer grade gasoline. A third fuel, a combination of the winter and summer grades, was blended for a series of intermediate experiments. Test fuel specifications listing the mean and range of % paraffins, % olefins, % aromatics, average carbon number, and Reid Vapor Pressure in pounds/square inch (RVP in psi) are detailed in Table 1. The winter fuel used was typical of winter fuels with nominal 35.7% paraffins, 10.7% olefins, 51.2% olefins, and 12.9 RVP specifications. The summer fuel, obtained from Sun Refining and Marketing Company, was somewhat atypical of summer fuels, in that it was blended from feedstocks on hand in December 1986,

and therefore had lower paraffinic and olefinic content than is typical of summer grade fuels. That is, the Motor Vehicle Manufacturers 1985 national summer grade gasoline survey indicated an average paraffinic content of 58.6% (versus 47.5% in this study), an olefinic content of 6.7% (versus 4.8% here), and an aromatic content of 34.7% (versus 46.0% here) (2). The test fuel's RVP range of 10.1 - 11.0 was typical of summer grade fuels. This fuel was used as is, since it was all that was obtainable at that time.

The ranges associated with the mean values listed in Table 1 are an indication of fuel weathering and aging that occurred over the 6-month duration of the study. For example, during the first series of winter fuel tests, in December 1986, the fuel RVP was 13.1 psi, and by the time the last series was completed in April 1987, the RVP had dropped to 12.6 psi. The RVP decrease was accompanied by an increase in fuel average carbon number from 7.07 to 7.17, a paraffinic decrease from 36.5% to 33.5%, an olefinic decrease from 10.8% to 10.0%, and an aromatic increase from 50.2% to 54.4% -- all indicative of the loss of the most volatile fuel hydrocarbon components of propane, isobutane, n-butane, and isopentane. Comparisons of test fuel composition by carbon number distribution are given in Table 2 and depicted in Figures 2 and 3 respectively. Complete dispensed fuel specifications are detailed in Appendix 1.

Fuel Handling - The fuel handling schematic for the refueling study is depicted in Figure 4. Gasoline stored in a 10,000 gal underground storage tank was transferred by tank truck to a 750 gal underground tank adjacent to the test facility. It was then transferred to a modified CEXI fuel cart from which it was dispensed to the vehicle. The fuel cart consisted of a 60 gal stainless steel tank fitted externally with heating and cooling equipment and control circuitry (utilizing a Thermal Care/Mayer microcomputer liquid

temperature controller), designed to maintain the test fuel at any desired test temperature from about 0°F to 100°F. The fuel was delivered from the cart to the vehicle's fuel tank via a UL approved Tokheim gasoline pump, flow meter and totalizer similar to those used in gasoline service stations. The fuel delivery hose utilized a bypass design, thereby providing fuel at a constant temperature to a standard OPW 11-A automatic unleaded gasoline dispensing nozzle, from which gasoline was dispensed into the vehicle's fuel tank.

Sample Handling - The sample handling schematic is also depicted in Figure 4. Two types of samples were collected during the study: liquid fuel samples which were analyzed for fuel volatility (RVP measurement) and detailed hydrocarbon composition, and refueling vapor samples which were analyzed for both total and detailed hydrocarbon composition. In each refueling experiment, three RVP samples were taken: 1) from the thermostatted fuel cart prior to each test, 2) from the Grand Am's fuel tank before refueling began but after the 2.5 gal of initial fuel had thermally-equilibrated at its desired test temperature, and 3) from the Grand Am's fuel tank 15 minutes after the 10 gal refueling operation had occurred. Detailed hydrocarbon fuel analysis samples were similarly collected from the fuel cart, the initial tank fuel, and the final tank fuel. Vapor samples were collected from the refueling shed for total hydrocarbon analysis by a flame ionization detector (FID). Vapors were also collected in 60 liter Tedlar bags for detailed hydrocarbon analysis via gas chromatography (GC). RVP samples were analyzed according to ASTM Standard Test Method D-323-82 for Vapor Pressure of Petroleum Products (Reid Method). The Reid Method was calibrated bimonthly through analysis of two reagent grade hydrocarbons: pentane with an RVP of 15.6 psi and cyclopentane

with an RVP of 9.9 psi. In addition, intralaboratory comparison of RVP samples and standards was performed between the North Carolina Department of Agriculture's fuel analysis lab and EPA's in-house lab; all results, calibrations, and comparisons were satisfactory.

Total hydrocarbon mass emissions from the refueling operation were calculated using procedures outlined in SAE Recommended Practice J1043 for Instrumentation and Techniques for Vehicle Refueling Emissions Measurement. Detailed GC hydrocarbon analysis procedures identified 83 different C_3-C_{11} hydrocarbons for both liquid and vapor samples. The GC analytical procedure has been previously published (3).

Temperature Parameters - As was mentioned in the introduction, one of the most important factors in determining the magnitude of refueling emission is ΔT, the tank differential temperature, which is the difference between the tank fuel temperature, Tt, and the dispensed fuel temperatures, Td, (i.e. $\Delta T=Tt-Td$). In a 1985 EPA Technical Report by Rothman and Johnson concerning refueling emissions, a table was compiled (listed in Appendix 2 in its entirety) detailing weighted temperature and RVP parameters by seasonal, regional, and annual average (4). The weighted temperature parameters, ΔT and Td, from this table were taken from a survey conducted for the American Petroleum Institute by Radian Corporation (5). The RVP data from this table were taken from the 1983 ASTM maximum specifications for the United States (6). The maximum RVP specification were used on the assumption that recent increases in RVP would continue and that by 1989 in-use RVP levels would approach or be at the maximum value specified by ASTM. This has already proven to be the situation in some areas of the country (4).

The temperature and RVP parameters selected for this study are listed in Table 3, include many of the seasonal, regional, and annual "Weighted Temperature and RVP Parameter" scenarios described by Rothman and Johnson. Table 3, therefore, includes comparisons to Rothman and Johnson's RVP, Td, and ΔT data. The experimental intention here was to be as inclusive of as many applicable parameters as possible within the time, budget and experimental constraints of this study. For example, Rothman and Johnson's minimum Td and Tt were 52.0 and 51.7°F respectively, while their maximum were 90.5 and 98.8°F respectively. In this study, the minimum Td and Tt were 50 and 40°F respectively, while the maximum were 88 and 108°F respectively. Rothman and Johnson's minimum and maximum RVP values were 9.8 and 14.6 psi respectively; this study's were 10.1 and 13.2 psi respectively. Hence, most of Rothman and Johnson's RVP, Td, and ΔT parameters were included in the scope of this study.

Test Procedure - The refueling experiments were conducted using a Sealed Housing for Evaporative Determination (SHED) technique. The sealed housing or shed was fitted with sealable sampling ports, thermocouples, an air mixing system, a gas-tight neoprene port surrounding the gasoline delivery hose and nozzle, and a large neoprene gas-tight glove which allowed manipulation of the delivery hose and nozzle by the operator from outside the shed. Prior to and periodically during the refueling experiments, as part of the Quality Assurance plan, various background checks, and propane recovery and retention tests were performed to verify shed integrity. Results indicated that it was in compliance with the specifications set forth in the Federal Registrar for air-tightness (7). A diagram of the refueling shed and fuel cart is depicted in Figure 5.

Two general types of tank temperature tests were run during the study: tests above and below ambient temperature (~65°F). When Tt >65°F, the Grand Am's fuel tank was drained of all fuel prior to each refueling test and then filled with 2.5 gallons of test fuel. This simulated an initial (18% of capacity) fuel tank volume condition. The vehicle was then pushed into the shed and a heat blanket was fitted to the bottom exterior surface of the fuel tank to bring the tank fuel up to the desired test temperature of 68, 70, 78, 80, 88, 90, 98, or 108°F by heating at a moderate rate. The shed's interior temperature was likewise maintained at the desired test temperature of 68, 70, 78, 80, 88, 90, 98, or 108°F by use of supplemental heat lamps located within the shed. After the tank fuel had reached its proper temperature, a temperature differential of ±2°F between the vapor in the tank and the liquid fuel was maintained for a minimum of 15 minutes. At this time the shed was closed and sealed, an initial tank RVP and GC sample were taken, and background HC levels were measured using an FID. Via the neoprene glove port, the shed operator then uncapped the fuel tank and began filling the vehicle at a fuel flow of 5 gpm. The Grand Am was fueled with 10.0 gallons of dispensed fuel and the fuel tank recapped. The 10.0 gallons of dispensed fuel plus the 2.5 gallons that were already in there account for over 90% of the Grand Am's 13.5 gallon fuel tank capacity.

For those tests were Tt <65°F, the 2.5 gallons of initial tank fuel were cooled in a 3 gal gas can surrounded by dry ice to a temperature of -20°F. The cooled fuel was then dispensed into the Grand Am's fuel tank, the vehicle pushed into the shed, and the tank allowed to warm up to the desired tank test temperature of 40, 50, or 60°F. The fuel cart temperature was maintained at 50, 60, or 70°F temperature by a thermo-regulator which controlled the temperature to within ±1°F for the duration of the refueling test(s). After the

desired Tt was achieved, the shed was closed and sealed, an initial tank RVP and GC sample were taken, and background HC levels measured. The refueling test then proceeded per previously described practice. The most important difference between the tests were Tt < 65°F and those where Tt >65°F was that the Tt <65°F tests did not maintain the ±2°F temperature differential between the vapor in the tank and the liquid fuel for 15 minutes. Because the Grand Am was at ambient temperature (68°F) in the shed, since the shed was not refrigerated, the vapor headspace temperature was on the order of 3 to 20°F higher than the liquid fuel temperature at the time of refueling. Hence, the displaced headspace vapors were of a higher temperature than would have been found in normal practice. This was the best experimental compromise that could be accomplished in a non-refrigerated shed. This may have had some effect on the overall HC gram/gallon refueling emission results from the Tt <65°F experiments.

Hydrocarbons in the shed were continuously monitored with the FID to determine when the vapor had become thoroughly mixed with the shed air. In normal practice, the HC levels stabilized about 15 minutes after replacement of the gas cap. At that time the FID was calibrated with known concentrations of propane in air, and a total hydrocarbon measurement was taken. In addition, a final tank RVP and GC sample were taken and a shed sample was collected in a 60 liter Tedlar bag for subsequent detailed hydrocarbon GC analysis. The GC was programmed to identify 83 different C_3 - C_{11} hydrocarbons. Temperature and pressure in the shed and temperatures of the fuel cart, the delivered fuel and the vehicle's fuel tank were recorded at the beginning and end of each test also.

RESULTS AND DISCUSSION

Hydrocarbon g/gal Emissions - HC g/gal emissions as a function of fuel type and ΔT are listed in Table 4. HC emissions ranged from a minimum of 2.90 g/gal to a maximum of 7.41 g/gal; the winter fuel results averaged 4.28 g/gal, the blend results 4.61 g/gal, and the summer fuel results 5.13 g/gal; the overall average HC emission rate from all fuels was 4.69 g/gal. A plot of refueling HC emissions versus ΔT is depicted in Figure 6. The summer fuel and blended fuel data display predictable trends: 1) higher dispensed fuel temperatures yield higher emissions (at constant fuel RVP), i.e. Td = 88°F results > Td = 78°F > Td = 70°F results; 2) lower tank temperatures, relative to the dispensed fuel temperature, yield higher emissions, i.e. ΔT = 20°F results > ΔT = -10 > ΔT = 0 > ΔT = +10 > ΔT = +20°F results. The winter fuel, however, displays anomalous results: at Td = 50°F, there was a decrease in HC g/gal emissions with increasing Tt; at Td = 60°F, there was an increase in emissions with increasing Tt; and at Td = 70°F, there was an increase in emissions followed by a decrease , with increasing Tt. It is not clear why the winter fuel results displayed these varied patterns, although it is possible that the artificial cooling of the tank fuel (when Tt < 65°F, see Fuel Handling Section) may have had some influence. Several test replicates were performed to clarify the data. For example, an average of 4 refueling tests for each Td = 70°F data point were performed, yielding g/gal values of 4.92 ± 0.35 at Tt=60°F, 5.64 ± 0.22 at Tt = 70°F, and 4.41 ± 0.17 at Tt = 80°F. In general, the reproducibility of tests runs was quite good. Thus, although the winter fuel emission g/gal patterns seem somewhat unusual, the overall results (3.60 - 5.64 g/gal) are important and similar to those found by other investigators (4); therefore they will be used in the discussion of

"Nat'l Average Winter/Summer/Annual Refueling Vapor Scenarios".

Prediction Equation - A refueling emission factor prediction equation was developed from the 101 valid refueling tests in this study. The emission factor equation is formatted similar to those of others, and is based on the primary parameters studied here, ΔT, Td, and RVP, that affect refueling emissions (4). In this study ΔT varied from -20 to +20°F, Td varied from 50 to 88°F, RVP varied from 10.0 to 13.3 psi, while refueling emissions varied from 2.90 to 7.41 g/gal. The results of a multiple linear regression using all test data yielded the following equation:

$$HC\ g/gal = 1.225 - 0.0476\ (\Delta T) + 0.0592\ (Td) + 0.153\ (RVP)$$

The correlation coefficient $R^2 = 0.5893$ indicates that this linear model is not very adequate for predicting the refueling emission trends observed in this study. If $R^2 > 0.95$, for example, then one could predict from the parameter coefficients that: 1) a 10°F increase in ΔT would lower refueling emissions by $\sim$0.5 g/gal; 2) a 10°F increase in Td would increase refueling emissions by $\sim$0.6 g/gal, and 3) a 1 psi increase in RVP would increase refueling emissions by 0.15 g/gal. Unfortunately the scatter in the winter data ($R^2 < 0.50$) alone, prohibits making such predictions.

Refueling Vapor Composition - A summary characterization of refueling vapor detailing the mean and range of HC g/gal emissions, % paraffins, % olefins, % aromatics, and average carbon number is listed in Table 5. This Table is similar in format to the summary test fuel specifications listed in Table 1. A comparison of Table 1's mean value summarizing all the test fuels with Table 5's mean value summarizing all the refueling vapors is depicted in Figure 7. Paraffins dominate the refueling vapor composition (~80% level) while aromatics (49%) and paraffins (39%) dominate the fuel composition. Table 6 details the refueling vapor composition as a function of fuel type, Td, Tt, and ΔI for all fuel/temperature scenarios. It is apparent from Tables 4,5, and 6 that though the HC g/gal emission rate varied significantly with ΔT, the % paraffins, %olefins, % aromatics, and average carbon number of the refueling vapors did not. Fuel temperatures, therefore, had little effect on the composition of refueling vapors. Fuel type, however, had a bit more effect on the composition of refueling vapors, thought not as much as expected. Paraffins, which composed ~80% of the refueling vapor, were least affected by fuel type: winter vapors averaged 77% while summer vapors averaged 82%. Aromatics, which comprised the smallest fraction of the refueling vapor, ~6%, varied little with fuel type also. Only the % olefin fraction seemed fuel sensitive: winter vapors averaged 17% while summer vapors averaged 10%. This is reflective of fuel % olefins differences, with winter fuel containing 10.7% and summer fuel 4.8% olefins. N-butane, isopentane, isobutane, and n-pentane ranked as the most abundant HC compounds, comprising ~70% of winter, summer, and blended refueling vapors.

Seasonal Scenarios - Three seasonal scenarios will be discussed in this section: 1) the national average winter scenario (October-March) with Td = 60°F, Tt = 60°F, ΔT = 0°F, RVP = 12.9 psi, and HC = 4.23 g/gal; 2) the

national average summer scenario (April-September) with Td = 78°F, Tt = 88°F, ΔT = +10°F, RVP = 10.3 psi, and HC = 4.26 g/gal; and 3) the national annual average scenario (January - December) with Td = 70°F, Tt = 70°F, ΔT = 0°F, RVP = 13.2 psi, and HC = 5.64 g/gal. Table 7 details the refueling vapor carbon number distribution by seasonal scenario. Figure 8 plots the compositional refueling vapor Nat'l average seasonal scenario while Figure 9 plots the refueling vapor carbon number distribution for the Nat'l average scenarios. The data from Table 7 and Figure 8 indicate that compared to the winter and annual scenarios, the summer scenario vapors had a slightly greater fraction of paraffins, which dominated the overall vapor composition, and a slightly lesser fraction of olefins, which comprised between 10 and 17% of the vapor. Table 7 and Figure 9 indicate that the summer scenario had a greater abundance of C_3, C_4, and C_8 hydrocarbons, while the winter and annual average scenarios had significantly greater abundances of C_5 hydrocarbons. This trend becomes apparent in Table 8 which lists fuel and refueling vapor HC compounds by national average seasonal scenario.

Observation of Table 8 indicates that together the paraffins isobutane, n-butane, isopentane, and n-pentane comprise 70% of all refueling vapors from all scenarios. The winter and annual average scenarios' isobutane, n-butane, isopentane, and n-pentane fractions average 17.2, 33.0, 17.9, and 2.6% respectively while the summer scenario averages 11.4, 45.2, 13.1, and 2.0% respectively. The winter/annual average scenarios emit greater amounts of isobutane and isopentane; the summer scenario emits significantly greater butane. Butanes comprise ∿50% of the winter/annual average vapor and ∿57% of the summer vapor; pentanes comprise ∿21% of the winter/annual average and ∿15% of the summer vapor. The similarity of the fuel butane concentrations being at the same level is somewhat surprising, since winter fuels usually have

higher butane levels than summer fuels in order to ennance fuel volatility for cold weather operation. Correspondingly, winter scenarios usually have higher butane refueling vapor levels (8).

SUMMARY AND CONCLUSIONS

The main objective of this study was to determine the refueling emission rates from a 1986 Pontiac Grand Am using 3 test fuels, including a winter, summer, and intermediate blend gasoline, under a variety of seasonal temperature conditions. Refueling parameters examined included the hydrocarbon refueling vapor g/gal emission rate as a function of fuel volatility (RVP), dispensed fuel temperature (Td), and vehicle fuel tank temperature (Tt) variables. With the 3 test fuels, RVP varied from 10.0 to 13.3 psi, Td varied from 50 to 88°F, Tt varied from 40 to 108°F, while refueling emissions ranged from 2.90 to 7.41 g/gal. Winter fuel emissions averaged 4.28 g/gal, the blended fuel emissions averaged 4.61 g/gal, while the summer fuel averaged 5.13 g/gal. The overall hydrocarbon g/gal emission rate varied significantly with ΔT. With the summer and blended fuel, the following predictible HC refueling emission trends were observed: 1) higher dispensed fuel temperatures yielded higher emissions and 2) lower tank temperatures, relative to the dispensed fuel temperature, yielded higher emissions. The winter fuel displayed anomalous (unpredictible) refueling emission trends; no reason other than the artificial cooling of the tank fuel when Tt <65°F could be suggested to account for this. A refueling emission factor prediction model was developed from the test results in this study, but the data scatter in the winter fuel tests resulted in a flow coefficient of correlation with this model (R^2 = 0.59).

Detailed hydrocarbon analysis of the refueling vapors indicated that the vapor composition appeared independent of temperature and fuel type. That is, the refueling vapor was comprised primarily of paraffins (~80%), ~10-17% olefins, and ~5% aromatics within the various parameter limitations of this

study. Three national average seasonal refueling scenarios were identified by Td, Tt, and RVP parameter values by comparison to a refueling emissions study by Rothman and Johnson (4). The Nat'l average summer (April-September) scenario emission rate was 4.26 g/gal with vapro composition dominated by 11.4% isobutane, 45.2% n-butane, 13.1% isopentane, and 2.0% n-pentane. The Nat'l average winter (October-March) scenario emission rate was 4.23 g/gal while the National annual average scenario emission rate was 5.64 g/gal; the winter and annual scenarios' vapor compositions were dominated by 17.2% isobutane, 33.0% n-butane, 17.9% isopentane, and 2.6% pentane. Higher vapor butane levels were observed in the summer scenario compared to the winter or annual scenario due to lower than expected fraction of butane in the winter fuel.

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The content of this publication does not necessarily reflect the views or policies of the U.S. Environmental Protection Agency, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

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Table 1. TEST FUEL SPECIFICATIONS

Fuel Type	Paraffins, %	Olefins, %	Aromatics, %	Average Carbon Number	Reid Vapor Pressure (psi)
Winter Grade					
Mean	35.7	10.7	51.2	7.13	12.9
(Range)	(32.8 - 38.7)	(10.0 - 11.9)	(47.2 - 55.2)	(7.06 - 7.18)	(12.7 - 13.1)
Blended Fuel					
Mean	39.4	7.7	50.7	7.33	10.9
(Range)	(38.4 - 40.6)	(7.5 - 8.1)	(49.3 - 51.8)	(7.29 - 7.38)	(10.8 - 11.0)
Summer Grade					
Mean	47.2	4.8	46.0	7.45	10.4
(Range)	(44.4 - 48.4)	(4.6 - 5.0)	(44.6 - 48.7)	(7.42 - 7.50)	(10.1 - 11.0)
All Fuels					
Mean	39.5	7.7	49.0	7.30	11.5
(Range)	(32.8 - 48.4)	(4.6 - 11.9)	(44.6 - 55.2)	(7.06 - 7.50)	(10.1 - 13.3)

TABLE 2. TEST FUEL COMPOSITION

Carbon Number	Winter Fuel				Fuel Blend				Summer Fuel			
	Paraffins %	Olefins %	Aromatics %	% of Total	Paraffins %	Olefins %	Aromatics %	% of Total	Paraffins %	Olefins %	Aromatics %	% of Total
C3	0.06	0.00	0.00	0.06	0.12	0.00	0.00	0.12	0.10	0.00	0.00	0.10
C4	6.75	0.92	0.00	7.67	6.44	0.72	0.00	7.16	7.12	0.54	0.00	7.66
C5	9.14	5.26	0.00	14.34	6.54	3.73	0.00	10.26	5.33	1.56	0.00	6.89
C6	4.32	2.59	1.51	8.43	5.35	1.52	0.89	7.75	5.97	0.65	0.66	7.27
C7	2.41	0.80	23.20	26.41	1.75	0.44	21.84	24.02	2.40	0.61	16.67	19.68
C8	8.81	1.28	8.79	21.59	14.42	1.68	11.57	29.78	20.62	1.48	14.17	37.93
C9	1.76	0.00	10.80	12.56	1.94	0.00	10.63	12.56	2.58	0.00	9.92	12.50
C10	1.87	0.00	6.44	8.30	2.62	0.00	5.11	7.73	2.54	0.00	4.58	7.12
C11	0.58	0.00	0.00	0.64	0.64	0.00	0.00	0.64	0.85	0.00	0.00	0.85
Total	35.70	10.70	50.74	*7.14	39.84	8.09	50.04	*7.31	47.51	4.84	46.00	*7.43

*Denotes Average Carbon Number Value

TABLE 3. EXPERIMENTAL TEMPERATURE AND RVP PARAMETERS

Fuel Type	Cart Temp Td, °F	Tank Temp Tt, °F	ΔT, °F	Dispensed Fuel RVP, psi	Comparison to Rothman and Johnson, Reference 4			
					Maximum RVP, psi	Td, °F	ΔT, °F	Scenario by Region, Season
Winter	50	40	-10	12.5				
Winter	50	50	0	12.7	14.6	52.0	-0.3	N. East Region, Winter (Oct.-Mar)
Winter	50	60	+10	12.7				
Winter	60	40	-20	13.0				
Winter	60	50	-10	13.0	12.8	61.8	-0.4	S. West Region, Winter (Oct-Mar)
Winter	60	60	0	12.9	13.9	60.3	-0.8	*Nat'l Avg. Winter (Oct-Mar)*
Winter	60	70	+10	13.3	13.3	62.3	+5.7	N. East Region, Annual Average
Winter	60	80	+20	12.7				
Winter	70	60	-10	12.8				
Winter	70	70	0	13.2	12.6	68.9	+4.4	*Nat'l Annual Average*
Winter	70	80	+10	13.1				
Blend	70	50	-20	11.0				
Blend	70	60	-10	10.8				
Blend	70	70	0	11.0	11.4	70.5	+3.7	S. West Region, Annual Average
Blend	70	80	+10	10.9	12.2	70.7	+10.7	N. East Region, Summer (Apr-Oct)
Blend	70	90	+20	10.8				
Summer	70	60	-10	11.0				
Summer	70	70	0	10.5				
Summer	70	80	+10	10.3				
Summer	78	68	-10	10.6				
Summer	78	78	0	10.3	10.5	77.2	+3.3	Far West Region, Summer (Apr-Oct)
Summer	78	88	+10	10.3	11.5	76.2	+8.8	*Nat'l Avg. Summer (Apr-Oct)*
					11.3	78.8	+9.4	*Nat'l Avg. Ozone (May-Sept)*
Summer	88	68	-20	10.4				
Summer	88	78	-10	10.2				
Summer	88	88	0	10.3				
Summer	88	98	+10	10.2	11.2	88.0	+7.5	S. East Region, Ozone (May-Sept)
Summer	88	108	+20	10.1	11.3	86.5	+13.3	N. Central Region, Ozone (Jul-Aug)

TABLE 4. HYDROCARBON G/GAL EMISSIONS AS A FUNCTION OF FUEL TYPE AND TEMPERATURE

Fuel Type	Cart Temp. Td, °F	Tank Temp. Tt, °F	ΔT, °F	HC g/gal
Winter	50	40	-10	4.01
Winter	50	50	0	3.74
Winter	50	60	+10	3.60
Winter	60	40	-20	3.64
Winter	60	50	-10	3.83
Winter	60	60	0	4.23
Winter	60	70	+10	4.53
Winter	60	80	+20	4.55
Winter	70	60	-10	4.92
Winter	70	70	0	5.64
Winter	70	80	+10	4.41
Blend	70	50	-20	5.56
Blend	70	60	-10	5.29
Blend	70	70	0	4.94
Blend	70	80	+10	3.90
Blend	70	90	+20	3.35
Summer	70	60	-10	5.24
Summer	70	70	0	4.50
Summer	70	80	+10	4.00
Summer	78	68	-10	5.46
Summer	78	78	0	5.27
Summer	78	88	+10	4.26
Summer	88	68	-20	7.41
Summer	88	78	-10	7.06
Summer	88	88	0	5.91
Summer	88	98	+10	4.40
Summer	88	108	+20	2.90

TABLE 5. REFUELING VAPOR AS A FUNCTION OF FUEL TYPE

Vapor Source	HC, g/gal Emissions	Paraffins, %	Olefins, %	Aromatics, %	Average Carbon Number
Winter Fuel					
Mean	4.28	77.1	17.0	5.3	4.70
(Range)	(3.60 - 5.64)	(74.7 - 78.7)	(16.0 - 18.2)	(3.8 - 5.9)	(4.62 - 4.78)
Blended Fuel					
Mean	4.61	80.1	13.2	5.9	4.79
(Range)	(3.35 - 5.56)	(78.2 - 82.3)	(13.0 - 13.5)	(4.2 - 7.8)	(4.67 - 4.92)
Summer Fuel					
Mean	5.13	82.0	10.3	6.3	4.81
(Range)	(2.90 - 7.41)	(78.3 - 84.8)	(8.5 - 12.2)	(4.5 - 7.4)	(4.63 - 4.98)
All Fuels					
Mean	4.69	79.7	13.6	5.8	4.76
(Range)	(2.90 - 7.41)	(74.7 - 84.8)	(8.5 - 18.2)	(4.2 - 7.8)	(4.62 - 4.98)

TABLE 6. Refueling Vapor Composition As A Function of Fuel Type, Td, and Tt

Fuel Type	Cart Temp Td, °F	Tank Temp Tt, °F	ΔT, °F	Average Carbon #	Paraffins %	Olefins %	Aromatics %
Winter	50	40	-10	4.78	74.67	16.84	6.55
Winter	50	50	0	4.71	77.31	16.46	5.75
Winter	50	60	+10	4.71	77.83	15.95	5.37
Winter	60	40	-20	4.62	78.71	17.41	3.75
Winter	60	50	-10	4.65	78.64	17.02	4.35
Winter	60	60	0	4.72	76.75	17.20	5.82
Winter	60	70	+10	4.71	76.69	16.98	5.22
Winter	60	80	+20	4.78	76.23	16.33	5.86
Winter	70	60	-10	4.67	76.72	18.23	4.93
Winter	70	70	0	4.72	77.03	16.97	5.89
Winter	70	80	+10	4.66	77.42	17.72	4.76
Blend	70	50	-20	4.80	79.72	13.09	6.28
Blend	70	60	-10	4.82	79.71	13.31	6.14
Blend	70	70	0	4.67	82.26	13.18	4.18
Blend	70	80	+10	4.76	80.57	13.47	5.21
Blend	70	90	+20	4.92	78.19	13.00	7.81
Summer	70	60	-10	4.77	82.86	10.00	6.56
Summer	70	70	0	4.69	82.98	12.23	4.53
Summer	70	80	+10	4.63	84.84	10.29	4.68
Summer	78	68	-10	4.87	82.53	8.51	6.41
Summer	78	78	0	4.87	82.39	8.98	6.82
Summer	78	88	+10	4.78	83.46	9.79	6.03
Summer	88	68	-20	4.80	82.55	10.64	6.37
Summer	88	78	-10	4.74	82.66	10.81	6.01
Summer	88	88	0	4.98	78.31	9.97	6.91
Summer	88	98	+10	4.82	80.87	11.03	7.18
Summer	88	108	+20	4.97	78.95	10.49	7.36

TABLE 7. REFUELING VAPOR COMPOSITION BY SEASONAL SCENARIO

Carbon Number	Nat'l Avg. Winter (Oct-Mar) Scenario				Nat'l Avg. Sum. (Apr-Oct) Scenario				Nat'l Annual Average Scenario			
	Paraffins %	Olefins %	Aromatics %	% of Total	Paraffins %	Olefins %	Aromatics %	% of Total	Paraffins %	Olefins %	Aromatics %	% of Total
C3	0.54	1.07	0.00	1.61	1.33	1.22	0.00	2.55	0.42	1.00	0.00	1.42
C4	50.44	5.10	0.00	55.54	56.60	3.76	0.00	60.35	50.04	4.57	0.00	54.61
C5	20.37	8.32	0.00	28.69	15.15	3.42	0.00	18.58	21.09	8.49	0.00	29.57
C6	3.22	1.33	0.58	5.13	5.58	0.47	0.35	6.40	3.12	1.54	0.70	5.35
C7	0.88	0.23	2.97	4.09	0.88	0.22	2.79	3.88	0.79	0.25	3.40	4.44
C8	1.00	1.14	0.73	3.11	3.03	0.71	1.20	5.67	1.33	1.12	0.39	2.85
C9	0.04	0.00	0.84	0.88	0.22	0.00	1.07	1.30	0.11	0.00	0.76	0.87
C10	0.22	0.00	0.70	0.92	0.55	0.00	0.63	1.17	0.10	0.00	0.35	0.46
C11	0.03	0.00	0.00	0.03	0.12	0.00	0.00	0.12	0.00	0.00	0.00	0.00
Total	76.73	17.19	5.82	*4.72	83.46	9.80	6.04	*4.78	77.00	16.97	5.60	*4.72
This Study:	Td = 60°F, Tt = 60°F, RVP = 12.9 psi				TD = 78°F, Tt = 88°F, RVP = 10.3 psi				TD = 70°F, Tt = 70°F, RVP = 13.2 psi			
Reference 4:	Td = 60.3°F, Tt = 59.5°F, RVP = 13.9 psi				Td = 76.2°F, Tt = 85.0, RVP = 11.5 psi				Td = 68.9 °F, Tt = 73.3°F RVP = 12.6 psi			

*Average Carbon Number

TABLE 8. FUEL AND REFUELING VAPOR HC COMPOUNDS BY NAT'L AVERAGE SEASONAL SCENARIO

HC Compound	Nat'l Avg. Winter Scenario			Nat'l Avg. Summer Scenario			Nat'l Annual Avg. Scenario		
	Fuel % of total	Vapor % of total	Vapor g/gal Emission	Fuel % of total	Vapor % of total	Vapor g/gal Emission	Fuel % of total	Vapor % of total	Vapor g/gal Emission
Isobutane	1.74	17.63	0.75	1.02	11.44	0.49	1.86	16.77	0.94
N-Butane	5.10	32.81	1.39	5.92	45.17	1.92	5.42	33.27	1.85
Isopentane	7.30	17.60	0.75	4.18	13.05	0.55	7.75	18.13	1.01
N-Pentane	1.46	2.51	0.11	0.88	1.97	0.09	1.53	2.76	0.16
Total of above	15.60	70.55	3.00	12.00	71.63	3.05	16.56	70.93	3.96
(total HC g/gal emission rate from Table 4)			(4.23)			(4.26)			(5.64)

APPENDIX 1. TEST FUEL SPECIFICATIONS

Fuel Type	Cart temp Td, °F	Tank temp Tt, °F	Test Completion Date	Dispensed Fuel Average Carbon #	Cart RVP (psi)	Initial RVP (psi)	Final RVP (psi)	Dispensed Fuel		
								% Paraffins	% Olefins	% Aromatic
Winter	50	40	3/31/87	7.18	12.53	12.57	12.46	34.1	10.1	53.6
Winter	50	50	4/2/87	7.17	12.69	12.47	12.60	33.5	10.0	55.2
Winter	50	60	4/5/87	7.12	12.68	12.34	12.54	32.8	10.0	55.2
Winter	60	40	1/14/87	7.11	12.96	12.87	12.86	36.6	10.7	50.3
Winter	60	50	1/14/87	7.15	13.02	12.89	12.76	33.8	10.1	53.0
Winter	60	60	1/23/87	7.12	12.91	13.00	12.97	36.2	10.8	50.2
Winter	60	70	1/23/87	7.17	13.32	12.84	12.95	37.8	11.8	48.1
Winter	60	80	1/30/87	7.10	12.73	12.24	12.55	38.1	11.9	47.2
Winter	70	60	1/8/87	7.13	12.84	12.78	12.78	36.5	10.6	50.2
Winter	70	70	12/11/86	7.06	13.19	12.67	12.92	38.7	11.7	47.5
Winter	70	80	12/8/86	7.08	13.13	12.63	12.98	34.7	10.0	53.0
Blend	70	50	5/6/87	7.31	11.04	10.88	10.98	39.8	8.1	50.0
Blend	70	60	5/7/87	7.29	10.82	10.92	10.75	38.4	7.5	51.8
Blend	70	70	6/18/87	7.33	11.04	10.95	10.91	40.6	7.6	49.3
Blend	70	80	5/5/87	7.38	10.92	10.72	10.97	38.6	7.6	51.5
Blend	70	90	5/13/87	7.33	10.82	10.31	10.64	39.4	7.7	50.7
Summer	70	60	4/8/87	7.46	11.00	10.61	10.80	44.4	4.9	48.7
Summer	70	70	4/9/87	7.44	10.51	10.25	10.51	46.4	4.8	46.6
Summer	70	80	4/10/87	7.43	10.25	9.84	10.15	47.5	4.8	46.0
Summer	78	68	4/14/87	7.46	10.62	10.51	10.55	47.6	5.0	45.7
Summer	78	78	4/15/87	7.49	10.29	9.99	10.13	48.4	4.7	44.6
Summer	78	88	4/16/87	7.43	10.30	9.99	10.33	45.9	4.6	47.4
Summer	88	68	4/17/87	7.44	10.35	10.02	10.10	46.9	5.0	46.4
Summer	88	78	4/21/87	7.44	10.23	10.02	10.16	48.4	4.8	46.0
Summer	88	88	4/22/87	7.50	10.29	9.74	10.09	47.7	4.9	44.9
Summer	88	98	4/26/87	7.49	10.20	9.48	10.06	47.8	4.6	44.7
Summer	88	108	4/28/87	7.42	10.13	9.02	10.12	48.1	4.9	45.3

APPENDIX 2

Table 6, pages 48-49, reprinted from "Refueling Emissions From Uncontrolled Vehicles," EPA Technical Report EPA-AA-SDSB-85-6 by D. Rothman and R. Johnson, U.S. Environmental Protection Agency, Ann Arbor, MI, August 1985.

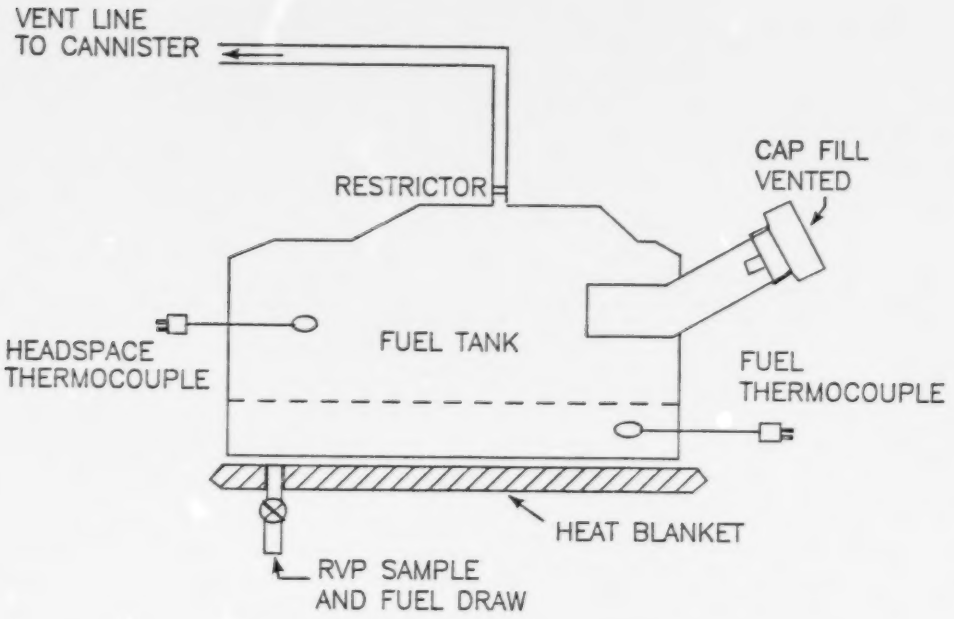
Table 6

Weighted Temperature and RVP Parameters

		REGION:				
SCENARIO:	Nat'l Avg.	1 N.East	2 S.East	3 S.West	4 N.Cent.	5 Far W.
Average Annual						
Fuel Consumpt. (gal x 10^6)	96,050.4	41,658.5	20,381.2	11,977.6	10,225.6	11,807.6
% Total	100.0	43.4	21.2	12.5	10.6	12.3
RVP (PSI)	12.6	13.3	12.4	11.4	12.6	11.7
Δ T (°F)	+4.4	+5.7	+4.0	+3.7	+5.5	+0.1
T_D (°F)	68.9	62.3	81.8	70.5	66.2	70.5
Summer (Apr-Oct)						
Fuel Consumpt. (gal x 10^6)	51,846.3	22,815.1	10,689.0	6,232.4	5,690.2	6,419.7
% Total	100.0	44.0	20.6	12.0	11.0	12.4
RVP (PSI)	11.5	12.2	11.4	10.1	11.2	10.5
Δ T (°F)	+8.8	+10.7	+6.8	+7.6	+11.7	+3.9
T_D (°F)	76.2	70.7	86.7	78.6	74.3	77.2
Winter (Oct-Mar)						
Fuel Consumpt. (gal x 10^6)	44,204.4	18,843.5	9,692.1	5,745.3	4,535.5	5,388.0
% Total	100.0	42.6	21.9	13.0	10.3	12.2
RVP (PSI)	13.9	14.6	13.4	12.8	14.3	13.3
Δ T (°F)	-0.8	-0.3	+0.9	-0.4	-2.4	-4.4
T_D (°F)	60.3	52.0	76.4	61.8	56.1	62.4
Ozone - 5 Mo. (May-Sept.)						
Fuel Consumpt. (gal x 10^6)	43,995.8	19,459.4	8,956.0	5,244.4	4,869.8	5,466.2
% Total	100.0	44.2	20.4	11.9	11.1	12.4
RVP (PSI)	11.3	12.0	11.2	9.9	10.9	10.3
Δ T (°F)	+9.4	+11.5	+7.5	+7.1	+12.1	+5.1
T_D(°F)	78.8	73.8	88.0	80.8	79.0	79.0
Ozone - 2 Mo. (Jul-Aug)						
Fuel Consumpt. (gal x 10^6)	18,664.7	8,326.2	3,760.0	2,147.7	2,103.0	2,327.8
% Total	100.0	44.6	20.1	11.5	11.3	12.5
RVP (PSI)	10.9	11.5	10.9	9.8	10.5	10.0
Δ T (°F)	+9.9	+12.5	+8.2	+7.0	+13.3	+3.2
T_D (°F)	82.7	78.0	90.5	83.5	86.5	83.0

Figure 1

1986 PONTIAC GRAND AM FUEL TANK



CAPACITY: 13.2 GALLONS
SIZE: 44" L x 20" W x 6" H

Figure 2. Test Fuel Composition

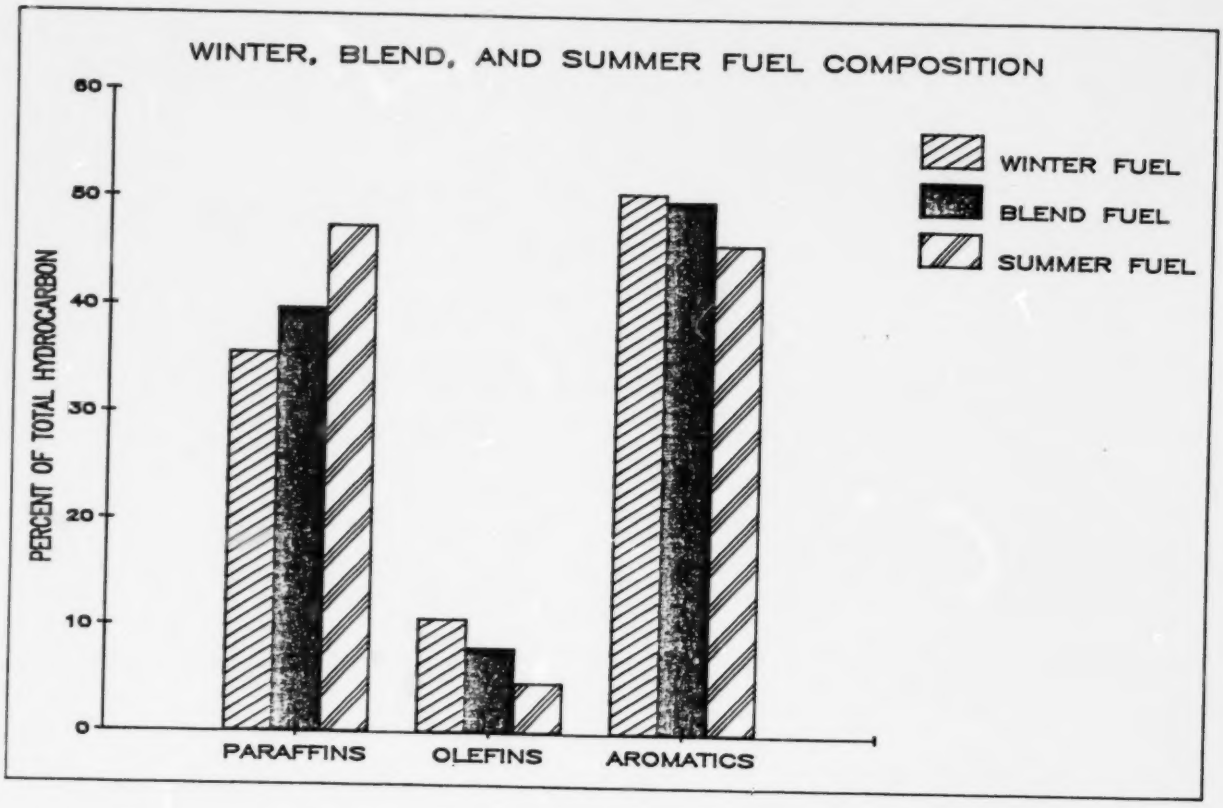
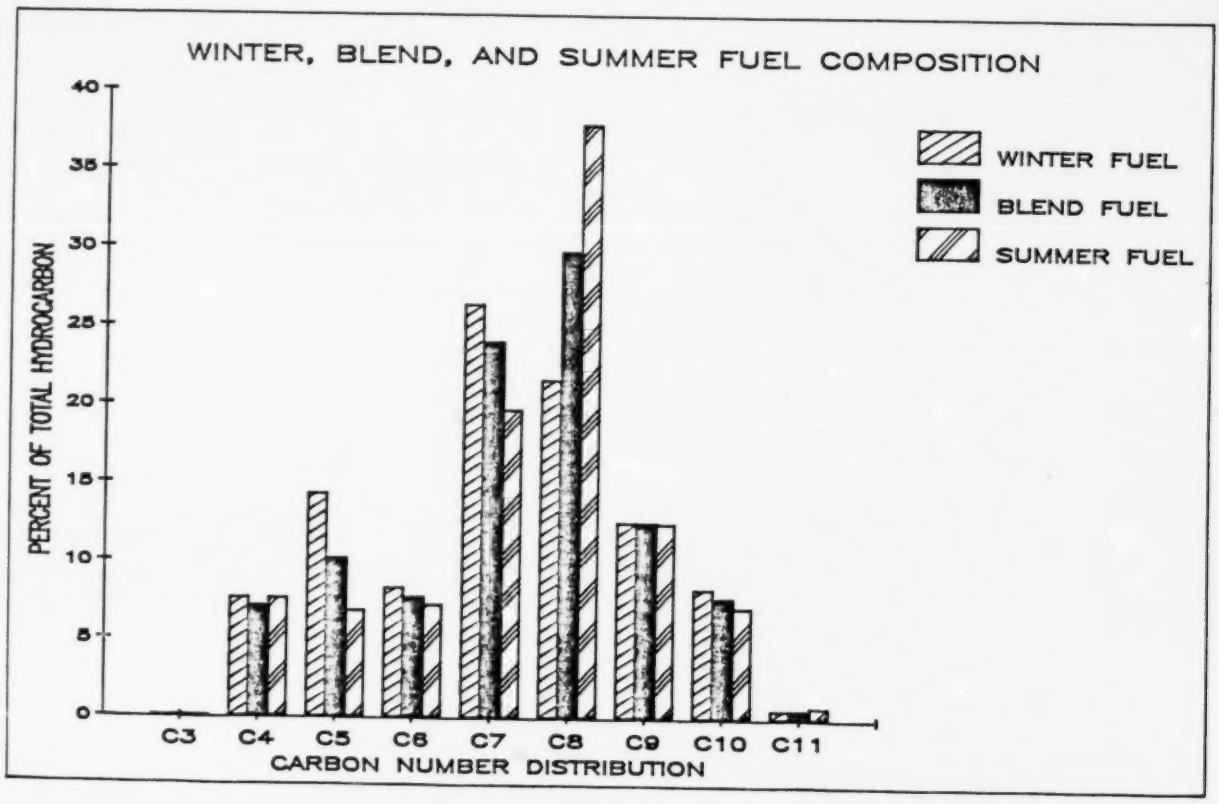
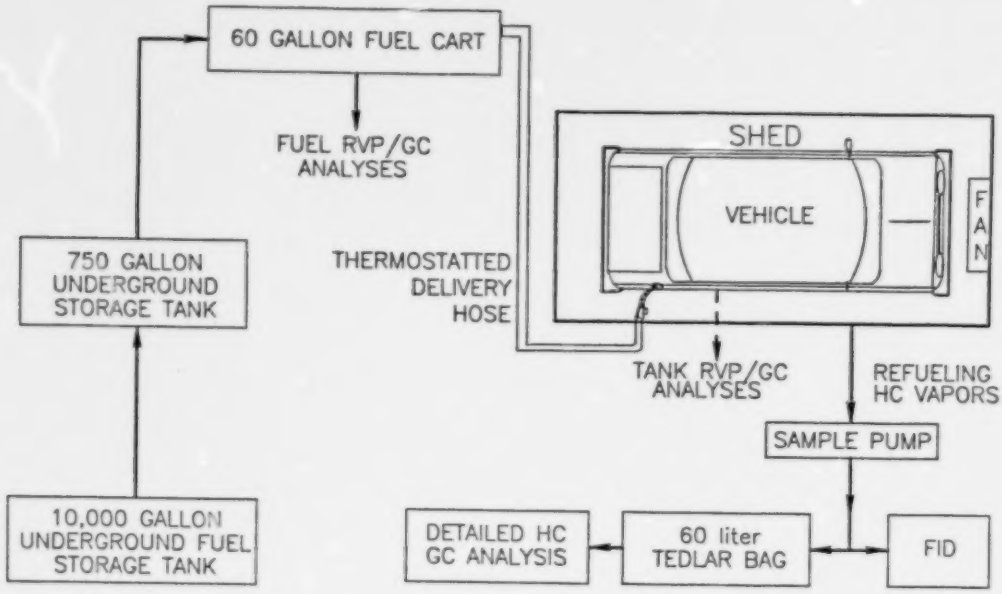


Figure 3. Test Fuel Composition by Carbon Number Distribution





Fuel/sample handling schematic

Figure 4

Sealed Housing for Evaporative and Refueling Emissions Determination

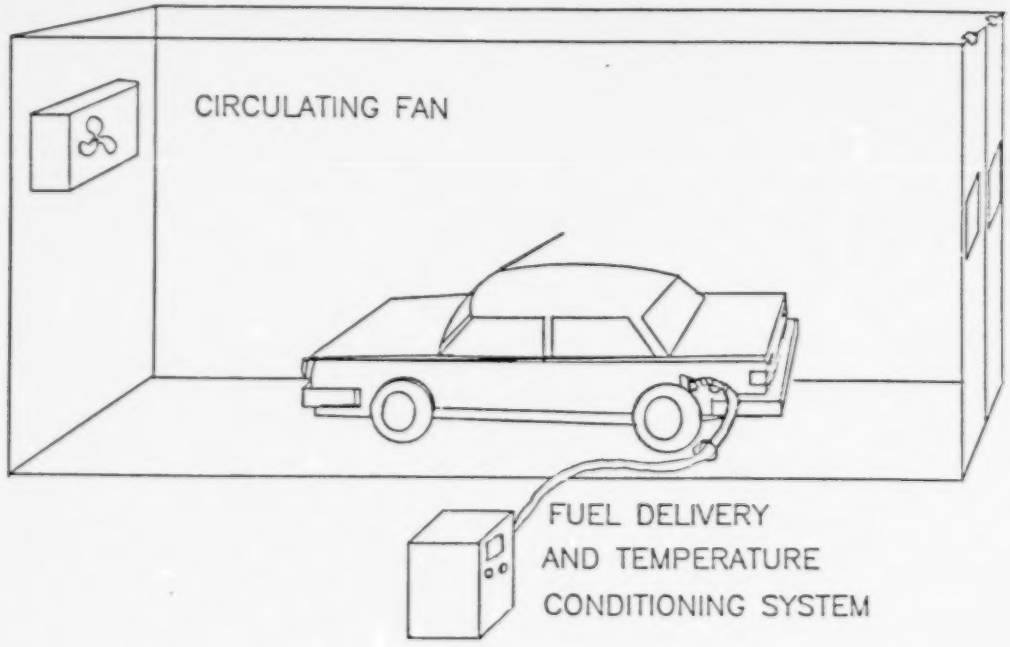


Figure 5

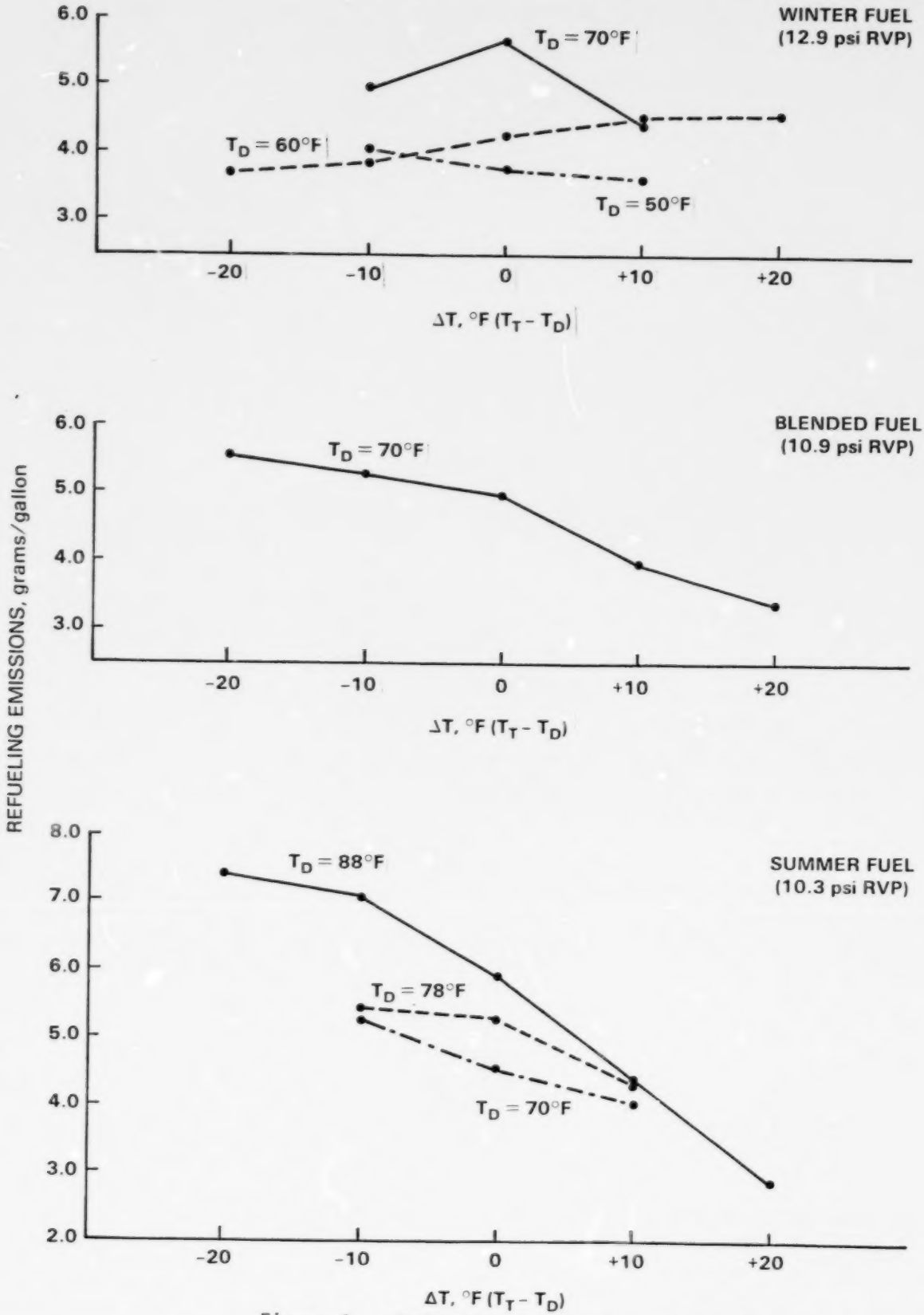


Figure 6. Refueling HC Emissions Versus ΔT

Figure 7. Comparison of Mean Value Test Fuel with Mean Value Refueling Vapor

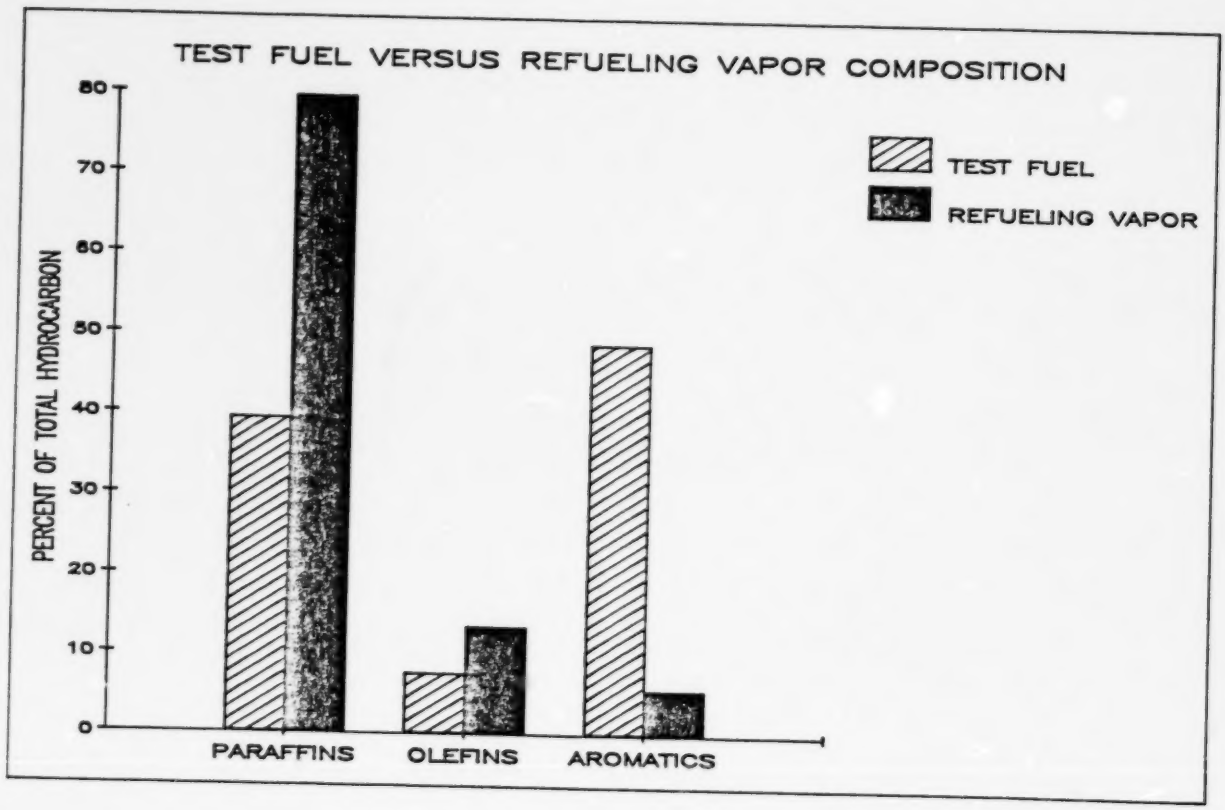


Figure 8. Nat'l Average Seasonal Scenario Composition

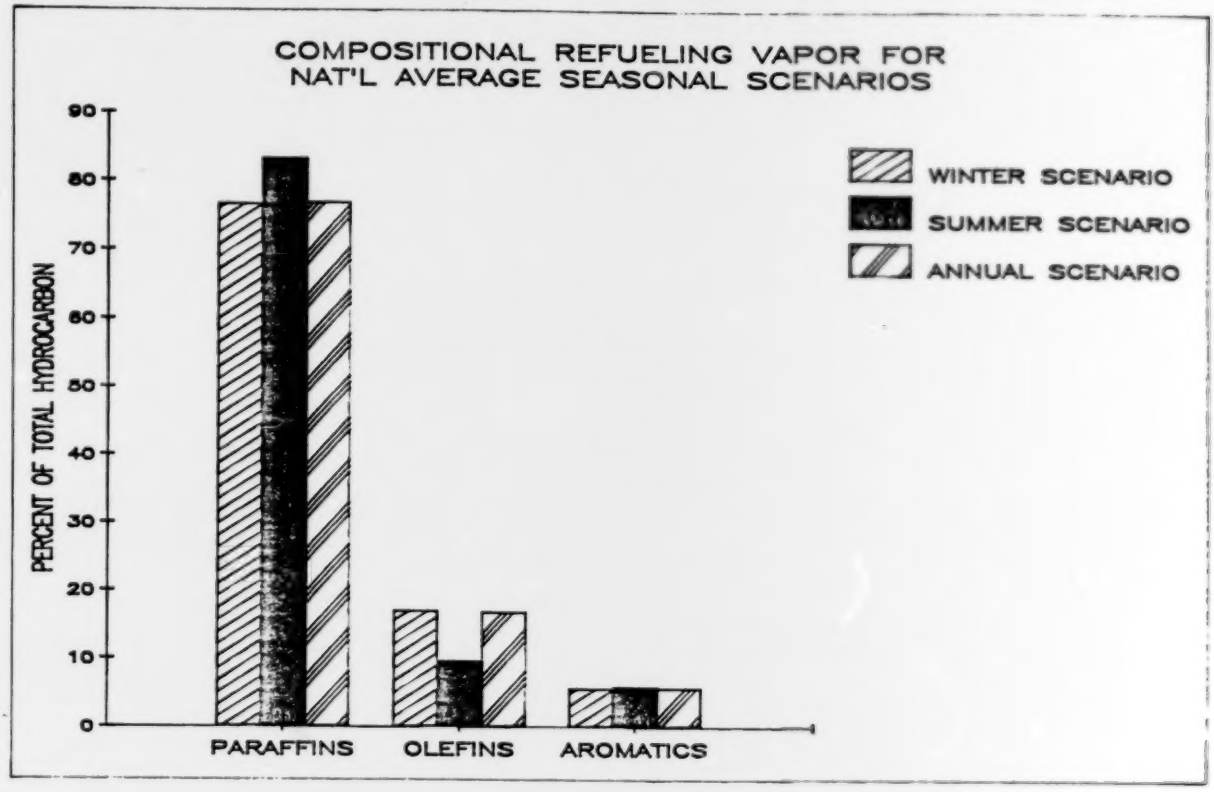


Figure 9. Carbon Number Distribution of Nat'l Average Scenarios